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A REFLEX TRIODE WITH GEOMETRIC FOCUSSING.(U)
JUN 79 A BROMBORSKY, H E BRANDT, R A KEHS
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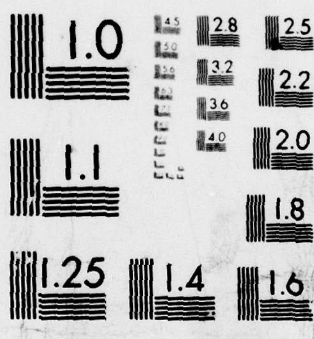

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Experimental results show that the ion beam generated by a simple reflex triode can be geometrically focussed, yielding an order of magnitude increase in current density (1.1 kA/cm^2) over a comparable nonfocussing triode geometry. Details are given for shaping the anode and cathode surfaces so that significant focussing can be achieved.

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1. INTRODUCTION

The reflex triode was one of the first intense pulsed ion sources[1] that could be adapted to the needs of pellet compression for controlled thermonuclear reactions. However, even though the triode can produce ion-current densities far in excess of the Langmuir-Child limiting current for unipolar ion flow,[2] further increase in ion current density over that obtained in the reflex triode is needed for the utilization of intense ion beams. Hence, some form of focussing must be applied to the ion beam after it emerges from the cathode of the triode.

Early in the development of the reflex triode,[1] it was suggested that the ion beam generated by the triode could be focussed by appropriately shaping the anode and cathode surfaces. If one ignores the effects of ion and electron space-charge fields, self-magnetic fields, external magnetic fields, self-electric fields, and fringing of the applied electric field, the appropriate electrode surfaces are sections of concentric spheres with the anode sphere located outside the cathode sphere. A simple single particle code calculation shows that the defocussing effect of the applied magnetic field is no greater than 0.5 mm for a typical proton in the experiment. The average quasi-static self-magnetic field ($r = 2.54$ cm) in the anode-cathode gap is 1.2 kG, giving a typical proton (~ 1 MeV) a gyroradius of 125 cm, which in turn gives a defocussing of 1.5 mm at the geometric focus. Thus, for the present experiment, the self-magnetic and external magnetic fields can be ignored. To determine the effects of the self electric field and fringing of the applied electric field requires more complicated simulations, which we cannot undertake yet. Hence, we assume the effects to be small enough so that a concentric spherical geometry will be a good proof of principal experiment for the concept of geometric focussing.

2. DESCRIPTION OF EXPERIMENT

A cross-sectional view of the experimental concentric spherical focussing geometry is shown in figure 1. The anode foil is 0.02-mm-thick polycarbonate film formed with a radius of curvature of 10 cm. The cathode is copper window screen formed with a radius of curvature of 8 cm. The on-axis separation between the anode and the cathode is 2 cm.

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[1] *S. Humphries, Jr., J. J. Lee, and R. N. Sudan, Generation of Intense Pulsed Ion Beams, Appl. Phys. Lett., 25, No. 1 (1 July 1974), 20.*

[2] *T. M. Antonsen, Jr., and E. Ott, Foil Scattering in a Reflex Triode Intense Ion Beam Accelerator, Appl. Phys. Lett., 28, No. 8 (15 April 1976), 424.*

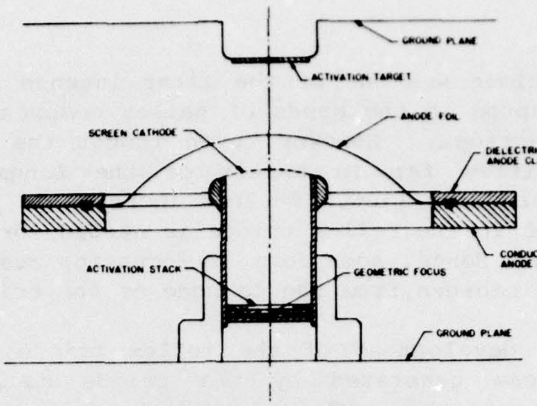

Figure 1. Cross-sectional view of reflex triode focussing configuration.

To produce a unidirectional focussed ion beam toward the cathode, the anode foil is clamped as shown in figure 1 with the conducting support ring located on the same side of the anode as the screen cathode.[3] This arrangement produces most of the anode plasma on the lower side of the foil due to surface flashover between the anode and the conducting support ring. Thus, most of the ions (>90 percent) propagate toward the screen cathode and not toward the upper ground plane.

The primary diagnostic tool for measuring ion current density is a carbon nuclear activation stack[4] placed in the 4.76-cm-diameter drift tube at varying distances behind the screen cathode. The carbon targets respond to bombardment by undergoing the nuclear reaction $^{12}C(p,\gamma)^{13}N(\beta^{+})^{13}C$. This reaction has a threshold energy of 0.43 MeV and a constant thick target yield[4] for proton energies between 0.5 and 1.6 MeV. Hence, by knowing the thick target yield for the reaction and the number of N^{13} activations produced during proton bombardment of the target and by assuming a reasonable proton energy spectrum, one can compute the number of protons that hit the target. Since N^{13} decays via positron emission, one determines the number of N^{13} activations using standard nuclear diagnostics.

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[3] *Alan Bromborsky, Howard E. Brandt, and R. Alan Kehs, Reflex Triode with Unidirectional Ion Flow, Harry Diamond Laboratories HDL-TM-78-22 (October 1978).*

[4] *F. C. Young, J. Golden, and C. A. Kapetanakos, Diagnostics for Intense Pulsed Ion Beams, Rev. Sci. Instrum.,* 48*, No. 4 (April 1977), 432.*

The target stack consists of four graphite disks 1.6 mm thick, and 4.76 cm in diameter. The lowest disk is solid; the disks above it are perforated with circular apertures 0.635 cm (0.25 in.), 1.27 cm (0.50 in.), and 2.54 cm (1.00 in.) in diameter. This arrangement of the targets allows mapping of the proton fluence for four adjacent radial intervals on one shot since the targets are sufficiently thick to stop any protons that hit them.

In addition to the target stack below the screen cathode, another target was placed 4.3 cm above the anode foil (fig. 1) to monitor the unidirectionality of the ion beam.

Average proton fluxes were computed by dividing the total proton fluence by the time that the applied voltage exceeded 0.43 MV.

The triode geometry shown in figure 1 was attached to an FX-45 pulse line. Typical operating characteristics for the triode in a focussing configuration with a 2-cm anode-cathode gap are a peak applied voltage of 1.0 to 1.5 MV and a pulse width of 15 to 20 ns (full width at half maximum). All data were taken with an applied magnetic field of 3.5 to 4.0 kG.

3. EXPERIMENTAL RESULTS

The diagnostic results for the focussing geometry are shown in figure 2. The sum of the average currents measured by all the activation targets varies from shot to shot between 0.50 and 1.60 kA due to our inability to control the amount of plasma formed during the anode flashover process.[3] Since different shots must be compared to determine the complete effect of the focussing geometry, all shots were normalized to a total average current of 17.8 A. This current corresponds to a current density of 1 A/cm^2 incident upon the cathode screen.

In figure 2, the on-axis proton flux peaks at a distance between 7 and 8 cm behind the cathode screen. This result agrees with predictions since the geometric focus was 8 cm behind the cathode screen. The peak normalized proton flux on axis is 13 A/cm^2, indicating an increase in proton flux more than an order of magnitude over the planar case. To check that a focussing factor of 13 was achieved, the geometry of figure 1 was changed so that the curved anode and cathode were replaced by planar ones with the 2-cm gap maintained.

[3]Alan Bromborsky, Howard E. Brandt, and R. Alan Kehs, *Reflex Triode with Unidirectional Ion Flow*, Harry Diamond Laboratories HDL-TM-78-22 (October 1978).

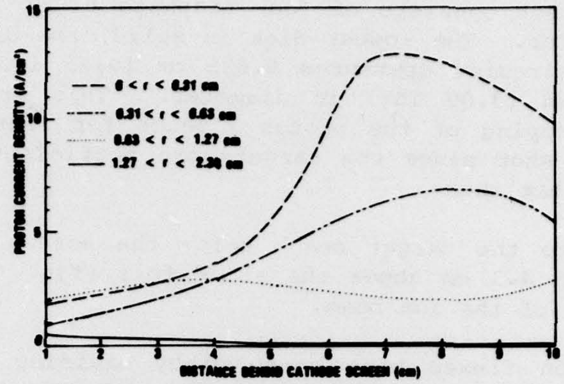

Figure 2. Map of proton flux in focussing triode geometry with input flux normalized to 1 A/cm^2.

The proton flux was then mapped by using the same technique as for the focussing geometry. The results of the mapping are shown in figure 3 (p. 9). The proton flux intensifies slightly near the axis in the planar geometry with normalized on-axis proton flux averaging (spatial average) 1.9 A/cm^2 between 7 and 8 cm behind the cathode screen. Thus, the effective focussing factor is between 6.8 and 11, depending on whether the normalized focussed flux is divided by the unfocussed flux or the normalized unfocussed flux is subtracted from the normalized focussed flux. The on-axis flux for the planar geometry is not a strong function (2 A/cm^2 ± 30 percent) of the distance behind the cathode screen (unlike in the focussing geometry where the on-axis flux varies between 2 and 13 A/cm^2). Therefore, the correct procedure for calculating the focussing gain is to subtract the planar on-axis flux from the maximum flux in the focussing geometry, yielding a gain of 11.

4. DISCUSSION OF RESULTS

The average (spatial) proton flux is a factor of two greater on axis than in the outer target annulus (1.27 cm < r < 2.38 cm) for the planar geometry, most likely because of the low aspect ratio (cathode diameter divided by anode-cathode gap) of the triode. The aspect ratio used in this experiment, 2.5, cannot be made much larger and still have successful diagnostic measurements because of the high source impedance (60 ohms) of the FX-45 pulse line. An increase in aspect ratio would lower the triode impedance and the peak applied voltage and cause ion beams with energies too low to accurately diagnose by using nuclear activation targets.

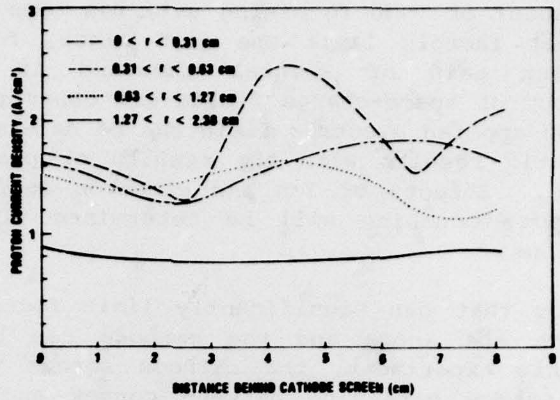

Figure 3. Map of proton flux in planar triode geometry with input flux normalized to 1 A/cm^2.

The dramatic effect of aspect ratio upon measured average ion current also can be seen by comparing the focussing geometry (2-cm gap), which produces an average ion current of 1.60 kA, with the planar unidirectional geometry,[3] which produces an average ion current of 3 to 7 kA across a 10-cm gap.

For the aspect ratio used in the focussing geometry (and the planar equivalent), *the effect of radially dependent space-charge fields* is probably one of the major causes of nonuniform proton flux at the cathode. The space-charge field of the reflexing electrons allows the ion current to exceed the Langmuir-Child limit for unipolar flow.[2] The greater the electron space charge field, the higher the ion current density. On axis, the electron space-charge fields are higher than anywhere else in the gap, so the maximum ion current density is on axis.

Another effect of the electron space-charge fields is that the ions enter the cathode screen nonnormally, thus focussing in a plane other than that containing the center of curvature of the anode and the cathode. The plane that an ion focusses in (where it crosses the z-axis) is then a function of where it leaves the cathode (r-coordinate). Such a functional dependence smears out the ion beam and reduces the maximum ion flux.

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[2]*T. M. Antonsen, Jr., and E. Ott, Foil Scattering in a Reflex Triode Intense Ion Beam Accelerator, Appl. Phys. Lett., 28, No. 8 (15 April 1976), 424.*

[3]*Alan Bromborsky, Howard E. Brandt, and R. Alan Kehs, Reflex Triode with Unidirectional Ion Flow, Harry Diamond Laboratories HDL-TM-78-22 (October 1978).*

Now that a factor of ~ 10 focussing gain has been achieved, it must be determined what factors limit the gain since, for most projected uses, a focussing gain of several thousand is required. The quantitative effect of space-charge fields and other perturbations such as fringing of the applied electric field can be determined by comparing the low-aspect-ratio results with the results of planned high-aspect-ratio experiments. Effects of ion and electron self-fields (magnetic and electric) upon focussing will be determined via two-dimensional computer simulations.

Another factor that can significantly limit focussing gain is the accuracy to which the anode and the cathode can be fabricated and aligned. For this experiment, the cathode screen was fabricated by clamping copper window screening between convex and concave machined surfaces with an 8-cm radius of curvature and by soldering the screen around the edge. The forming of the anode posed a greater problem since the anode had to be thin dielectric foil (a small fraction of an electron range) for the triode to produce a significant ion flux. Also, a new anode foil is required on every shot since firing the machine destroys the anode.

A further requirement for the anode material is that it must withstand large plastic deformations during shaping into a spherical surface. It was determined, after consultation with the National Bureau of Standards, that cast polycarbonate film (0.02 mm thick) manufactured under the trade name of Makrofol by the Mobay Chemical Co. fulfilled all requirements. The anode was formed from the Makrofol by clamping the foil in the anode support ring and pressurizing the foil until it became permanently deformed to the required spherical section. The radius of curvature of the deformation was monitored by resting a machined radius gauge (10 cm) directly on the pressurized foil. When the surface of the foil became coincident with the the surface of the gauge, the pressure was reduced, and the curvature of the plastically deformed anode foil was measured again to determine if material relaxation had changed the shape of the surface. It was found that the surface of the anode foil's central region was not affected by relaxation. However, near the clamp ring, the foil relaxed to the shape indicated in figure 1. Hence, foil relaxation did not create any problems with respect to the shape of the anode surface.

However, after relaxation, the spherical section was no longer centered with respect to the anode support ring. Thus, one could not align the anode and the cathode into concentricity by aligning the anode holder. To achieve concentricity of anode and cathode, a machined gauge was placed upon the cathode screen and in contact with the anode foil at five points when alignment was correct. After the anode was aligned and

locked in position, the alignment gauge was removed without damaging the anode. In the alignment procedure, the limiting factor in accurately aligning the anode and the cathode was the patience of the person making the adustments, the estimated concentricity error being 0.15 mm.

5. CONCLUSIONS

A reasonably simple technique has been demonstrated for geometrically focussing the output of a reflex triode. The focussing gain achieved was approximately 10 with a maximum absolute average proton flux of 1.1 kA/cm^2 at 8.1 cm behind the cathode screen. Anode and cathode fabrication and alignment have been detailed for the benefit of other experimenters who wish to use the geometric technique for focussing ion beams.

Future work on ion beam focussing will concentrate on detailed simulations of beam focussing to determine optimum geometries. In addition, the combination of geometric focussing and subsequent focussing by radiation cooling[5] will be investigated to determine if focussing gains of several thousand can be achieved with reasonable (100-kA) ion beam average currents. After determination of theoretical (simulation) feasibility, proof of principal experiments will be conducted.

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[5] *F. Winterberg, Focussing of Intense Ion Beams by Radiation Cooling in a Magnetic Mirror, Phys. Rev. Lett., 37, No. 11 (13 September 1976), 713.*

LITERATURE CITED

(1) S. Humphries, Jr., J. J. Lee, and R. N. Sudan, Generation of Intense Pulsed Ion Beams, Appl. Phys. Lett., 25, No. 1 (1 July 1974), 20.

(2) T. M. Antonsen, Jr., and E. Ott, Foil Scattering in a Reflex Triode Intense Ion Beam Accelerator, Appl. Phys. Lett., 28, No. 8 (15 April 1976), 424.

(3) Alan Bromborsky, Howard E. Brandt, and R. Alan Kehs, Reflex Triode with Unidirectional Ion Flow, Harry Diamond Laboratories HDL-TM-78-22 (October 1978).

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(5) F. Winterberg, Focussing of Intense Ion Beams by Radiation Cooling in a Magnetic Mirror, Phys. Rev. Lett., 37, No. 11 (13 September 1976), 713.

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